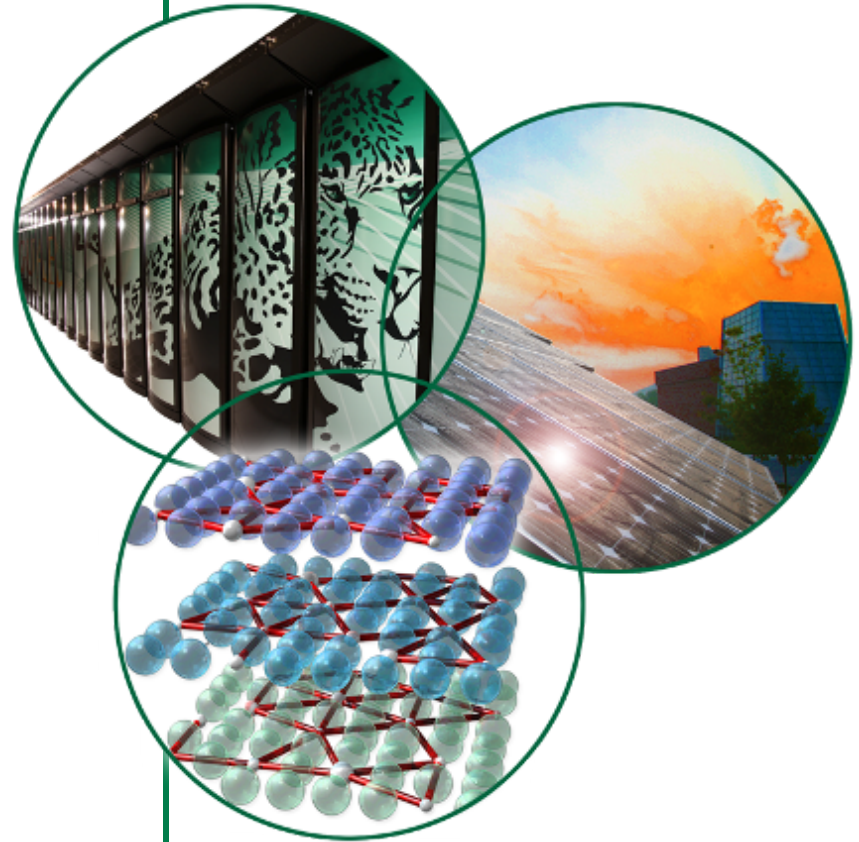# ORNL Nuclear Data Accomplishments for FY 2010

Mike Dunn, Luiz Leal, Klaus Guber, Doro Wiarda and Goran Arbanas

Reactor and Nuclear Systems Division

US DOE Technical Seminar
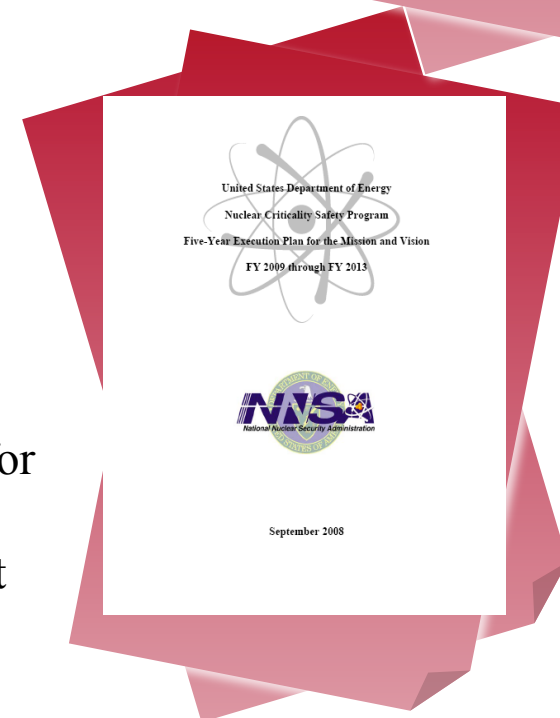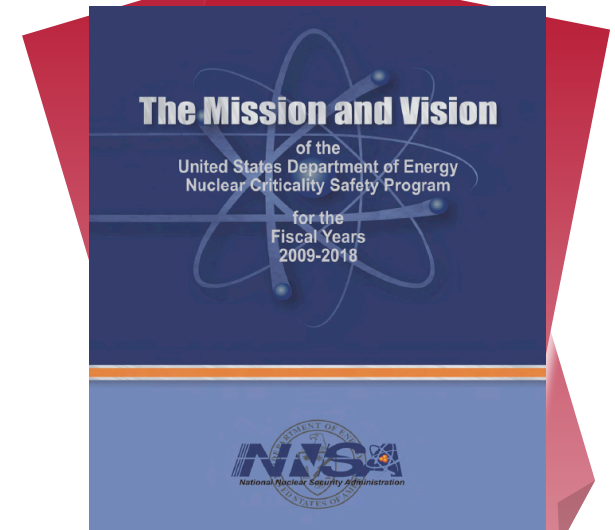Oak Ridge National Laboratory March 1 – 2, 2011

U.S. DEPARTMENT OF **ENERGY**

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Outline

➢ **ORNL NCSP Nuclear Data Program**

➢ **Measurements and Evaluations**

➢ **Status of Evaluations submitted to NNDC**

➢ **Summary**

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Nuclear Data Work for Criticality Safety

➤ ORNL Nuclear Data and Criticality Safety (NDCS) group provides technical support to NCSP working to develop and maintain state-of-the-art radiation transport (**SCALE**) and **nuclear data capabilities** for criticality safety applications

➤ ORNL **nuclear data contribution** to NCSP mission

- Cross-section measurements for resonance region (Data from facilities: IRMM, RPI, and ORELA)

- Nuclear modeling methods development (SAMMY)

- Cross-section evaluation and preparation of ENDF/B nuclear data files

- ORNL participation in international nuclear data activities:
  - OECD/NEA Working Party on International Nuclear Data Evaluation Cooperation (WPEC)
  - IAEA/CRP (Coordinated Research Projects)

- Cross-section processing methods development for generating nuclear data libraries (AMPX)

- Support radiation transport methods development and application

The Mission and Vision
of the
United States Department of Energy
Nuclear Criticality Safety Program
for the
Fiscal Years
2009-2018

United States Department of Energy
Nuclear Criticality Safety Program

Five-Year Execution Plan for the Mission and Vision

FY 2009 through FY 2013

September 2008

Resonance Region Nuclear Data Work for NCSP

➢ **Objective:** Provide measured and evaluated resonance-region cross-section data to address the priority NCSP nuclear data needs

➢ **Vision:** Addresses multiple Nuclear Data 5- and 10-year goals and attributes identified in the NCSP Vision

➢ **NCS Relevance:**

- Final product: rigorous ENDF/B resonance evaluations produced from cross-section measurements and analyses

- Integrates differential measurements, resonance region nuclear modeling, and cross-section evaluation capabilities (consistent with NCSP Nuclear Data Vision)—**provide resonance region differential data capability to address low and intermediate energy criticality safety needs.**

- ORNL 3-part nuclear data capability is well established and provides capability maintenance for a unique skill set and technical infrastructure for the U.S. (consistent with Defense Board recommendation and NCSP Vision)

- Leverages work through strong international collaborations (IRMM, OECD/ NEA, IAEA, CEA, KAERI, JENDL etc.) and domestic collaborations (LANL, BNL, ANL, and RPI) to address unique NCSP data needs
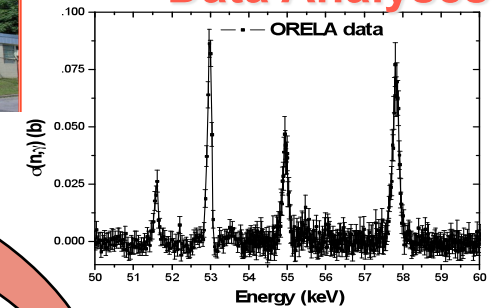
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High Energy Region
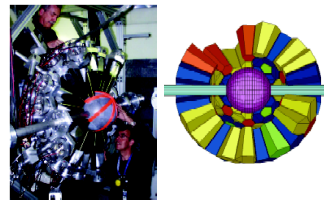
LANSCE

Resonance Region
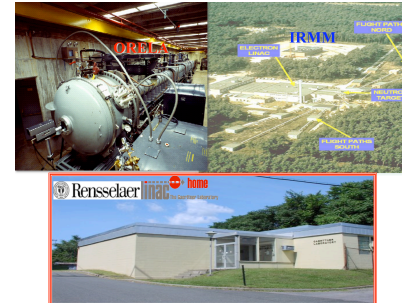
IRMM and RPI
Previous ORELA Data
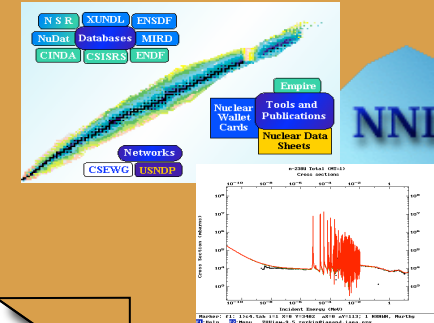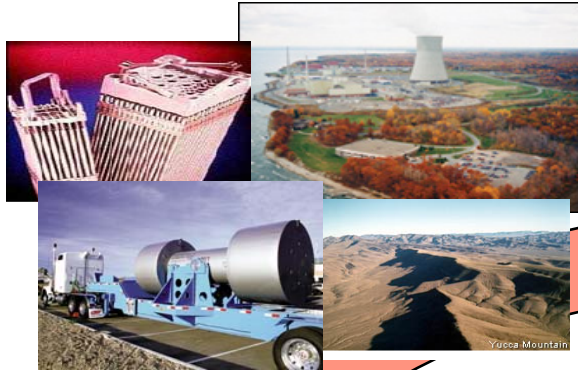
Data Analyses

Basic Science

Applications

**NCSP Data Support
for DOE Nuclear
Applications**

**Cross-Section
Evaluations**

**Evaluated Nuclear
Data Files (ENDF/B)**

NNDC

COG
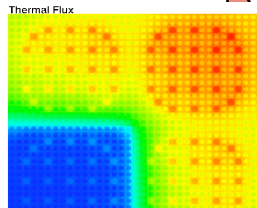
**AMPX   NJOY
PREPRO**
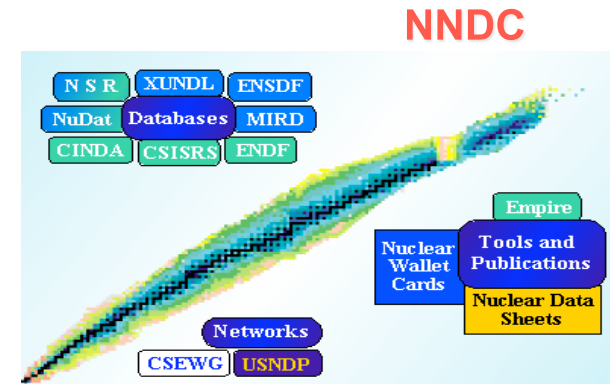
Computational modeling

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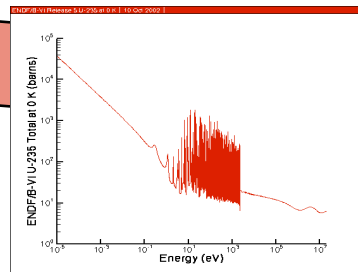
ORNL Measurement and Evaluations

➢ **ORNL Evaluation Contributions to ENDF/B during past 5 Years**

- ^{233}U, ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu, ^{237}Np, ^{232}Th,
- ^{155}Gd, ^{156}Gd, ^{157}Gd, ^{158}Gd
- ^{35}Cl, ^{37}Cl, ^{231}Pa, ^{239}Pa,
- ^{39}K, ^{40}K, ^{41}K, ^{19}F
- ^{55}Mn, ^{50}Cr, ^{52}Cr, ^{53}Cr, ^{54}Cr
- ^{58}Ni, ^{60}Ni
- ^{46}Ti, ^{47}Ti, ^{48}Ti, ^{49}Ti, ^{50}Ti
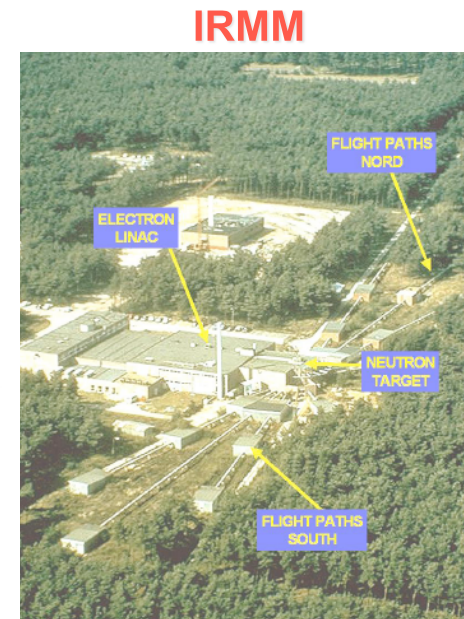- SiO_2

NNDC

➢ **FY10 Resonance Region Measurements**

- ^{182}W, ^{183}W, ^{184}W and ^{186}W (IRMM)
- ^{63}Cu and ^{65}Cu (IRMM)

➢ **FY10 Resonance Region Evaluation Tasks**

- ^{46}Ti, ^{47}Ti, ^{48}Ti, ^{49}Ti, and ^{50}Ti
- SiO_2 thermal evaluation NCSU-ORNL

IRMM

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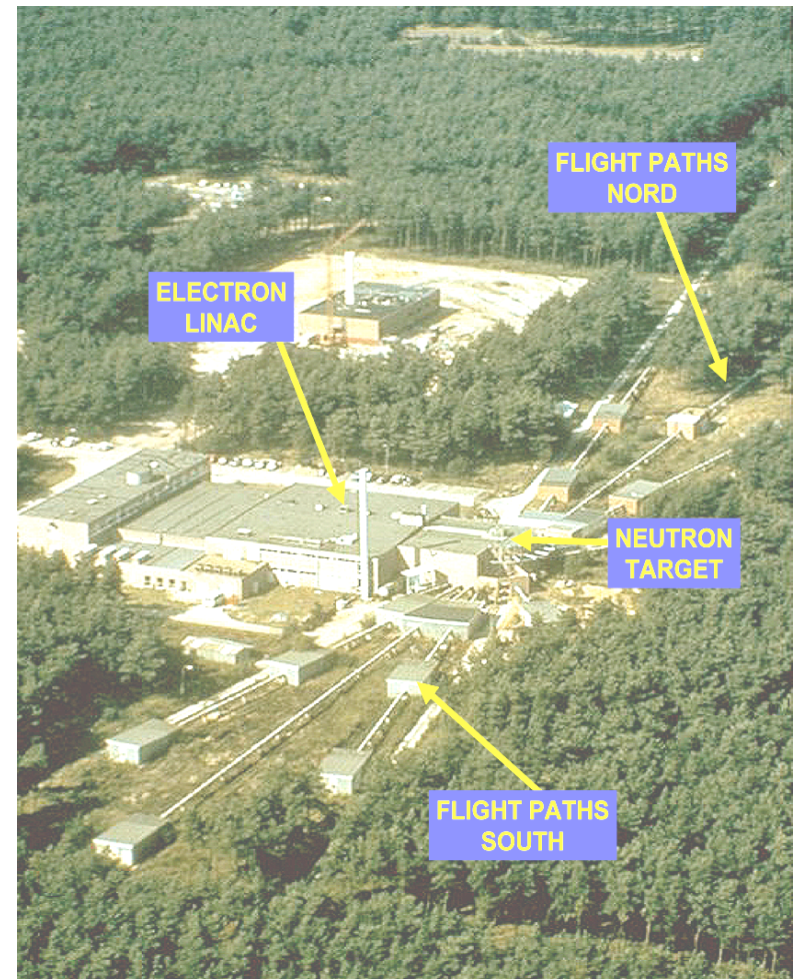
Geel Electron LINear Accelerator (GELINA)

GELINA Specifications

- **Time-of-flight facility**
- **Pulsed white neutron source**

  (10 meV < E_n < 20 MeV)
- **Multi-user facility with 10 flight paths (10 m - 400 m)**
- **The measurement stations have special equipment to perform:**
  - **Total cross section measurements**
  - **Partial cross section measurements**

Pulse Width	: 1ns		
Frequency	: 40 Hz	–	800 Hz
Average Current	: 4.7 μA	–	75 μA
Neutron intensity	: 1.6 10^{12} n/s	–	2.5 10^{13} n/s

ORNL-IRMM Team

- **Christos Lampoudis, IRMM**
- **Peter Schillebeeckx, IRMM**
- **Stefan Kopecky. IRMM**
- **Peter Siegler, IRMM**
- **Klaus Guber, Clint Ausmus, ORNL**

FLIGHT PATHS NORD

ELECTRON LINAC

NEUTRON TARGET

FLIGHT PATHS SOUTH

Neutron Production at GELINA

NEUTRON FLIGHT PATHS

NEUTRON TARGET

NEUTRON MODERATOR

ELECTRON BEAMLINE EXIT
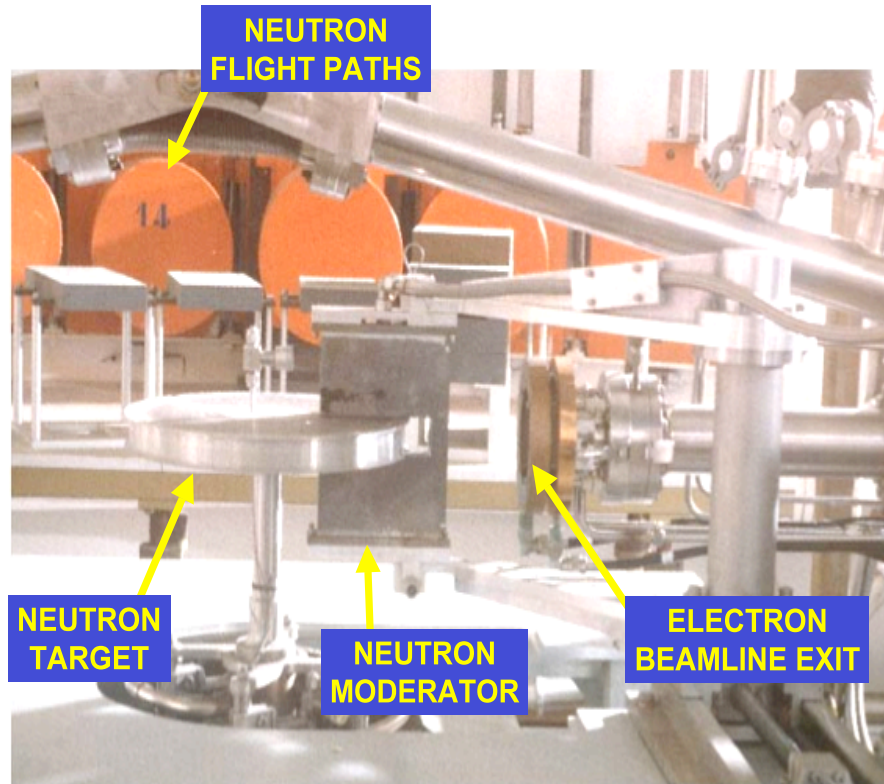
- e^- accelerated to $E_{e-,max} \approx$ 140 MeV

- (e^-, γ) Bremsstrahlung in U-target (rotating & cooled with liquid Hg)

- (γ,n) , (γ,f) in U-target

- Low energy neutrons by water moderator in Be-canning

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Capture cross section measurements at GELINA

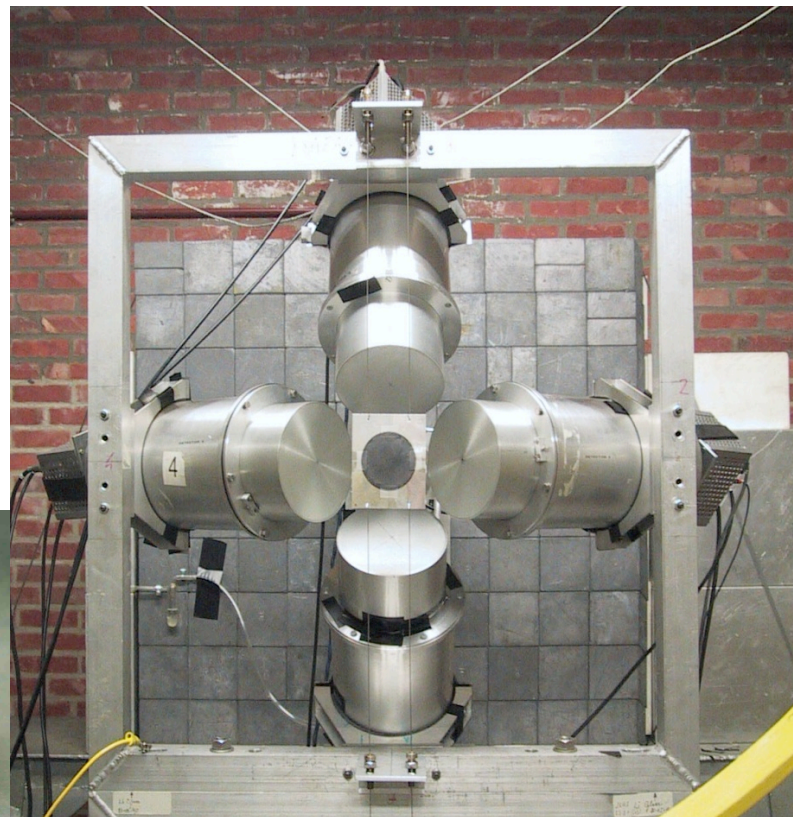## Total energy detection

- C$_6$D$_6$ liquid scintillators
  - 125°
  - PHWT
- Flux measurements (IC)
  - ^{10}B(n,α)
  - ^{235}U(n,f)

$$Y_{exp} = N\sigma_\varphi \frac{C_w - B_w}{C_\varphi - B_\varphi}$$

L = 10 m, 30 m and 60 m

WF : from MC simulations

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Transmission Measurements

Sample & Background Filters
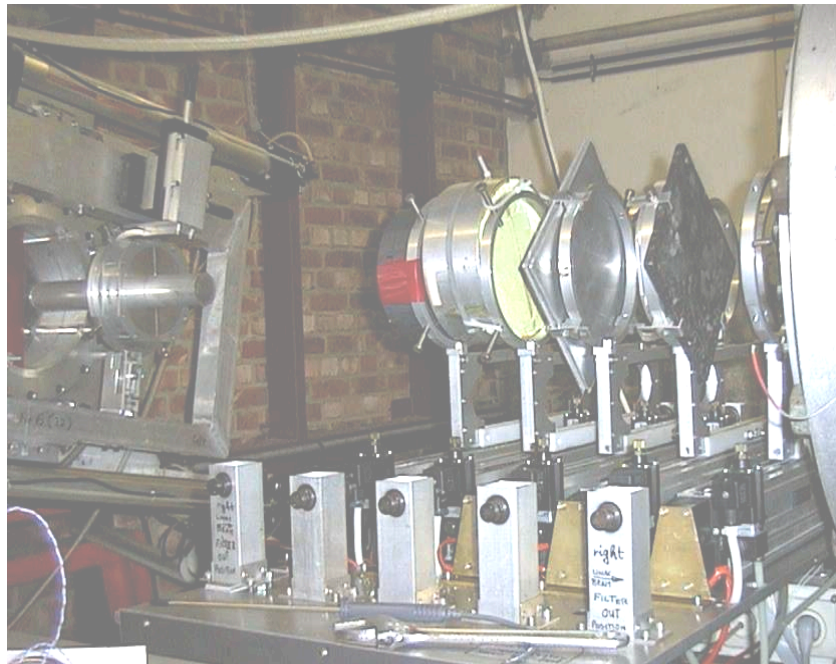
Detector

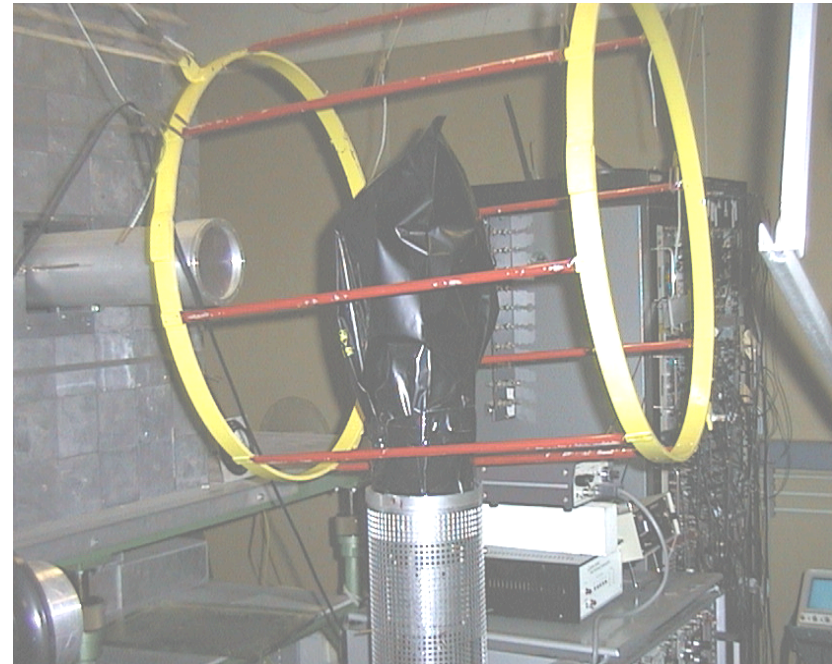**Detector stations**
**Moderated: L= 30 m,50 m,(100 m,200 m)**
Fast   : L= 400 m

Low energy : ^{6}Li(n,t)α Li-glass

High energy : H(n,n)H Plastic scintillator

ORNL Measurement Activities in FY10: I

- **Completed measurements for stable tungsten isotopes —enriched samples for ^{182,183,184,186}W .**

- **Data now covers complete resolved resonance region as well as part of the unresolved region.**

- **Normalization of the capture data finalized.**

- **Capture Data for ^{182,183,184,186}W from the high repetition run available to analyze.**

- **Transmission data for ^{184,186}W with different sample thickness available.**
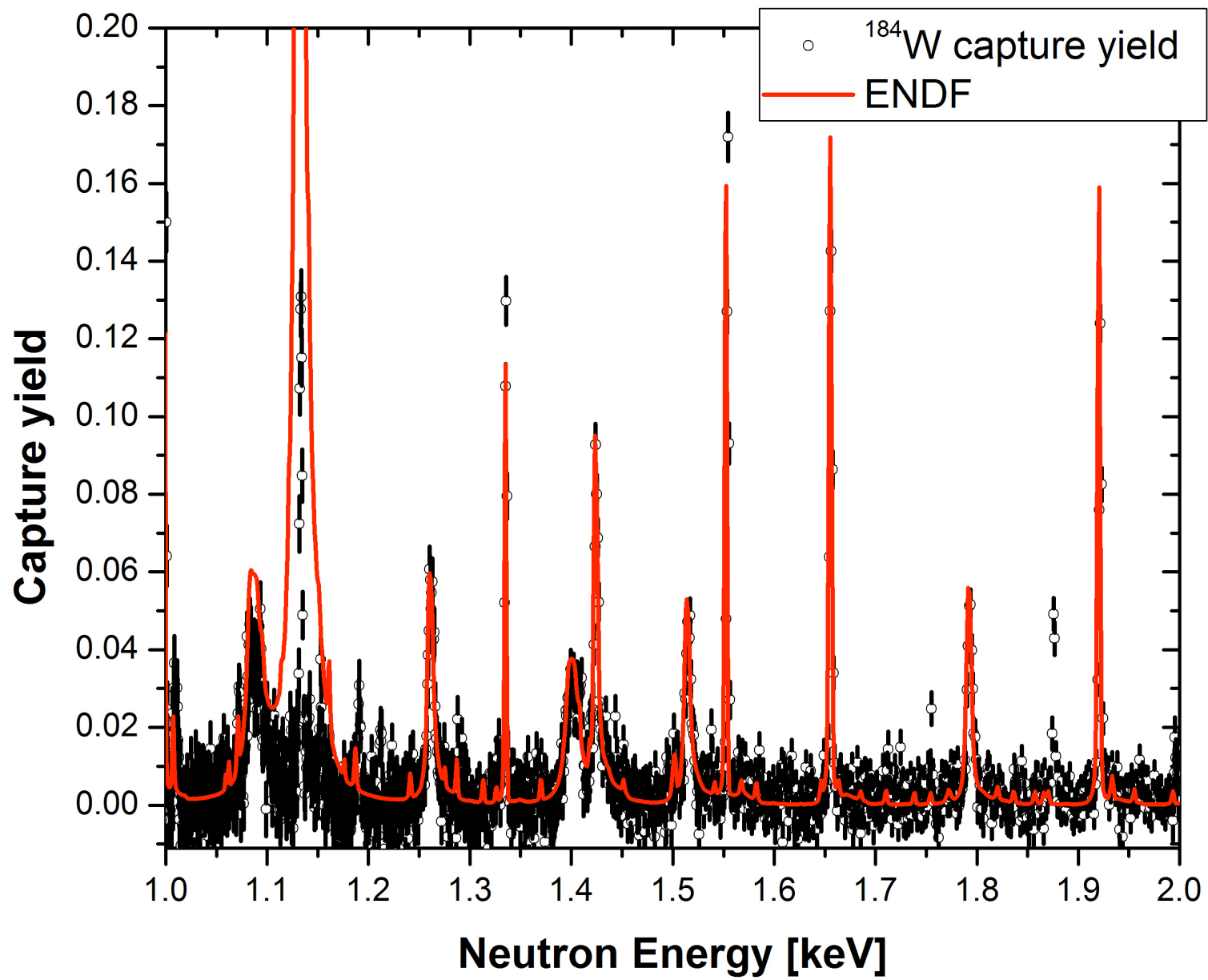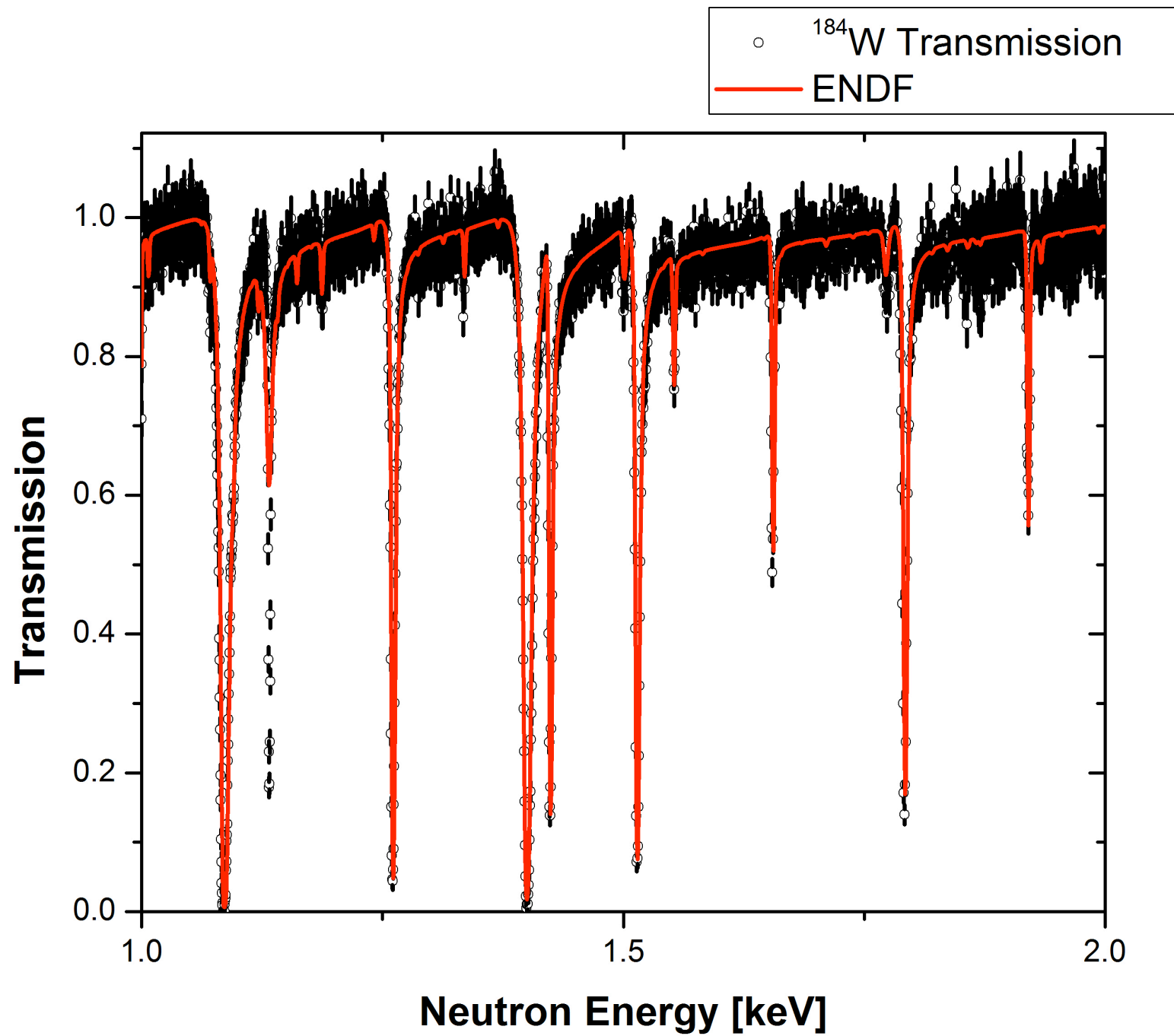
ORNL Measurement Activities in FY10: II

➤ **Neutron Capture measurements for ^{63,65}Cu at GELINA using set up at FP14, 60m station**

➤ **Neutron transmission on natural Cu using GELINA FP4, 50m station**

➤ **Use of metallic samples, >99% isotopic enrichments; 8cm diameter disks with 1mm thickness.**

➤ **Will include old ORELA transmission data in evaluation**

^{63}Cu (n,γ) Data

^{63}Cu (n,γ) Data - detail
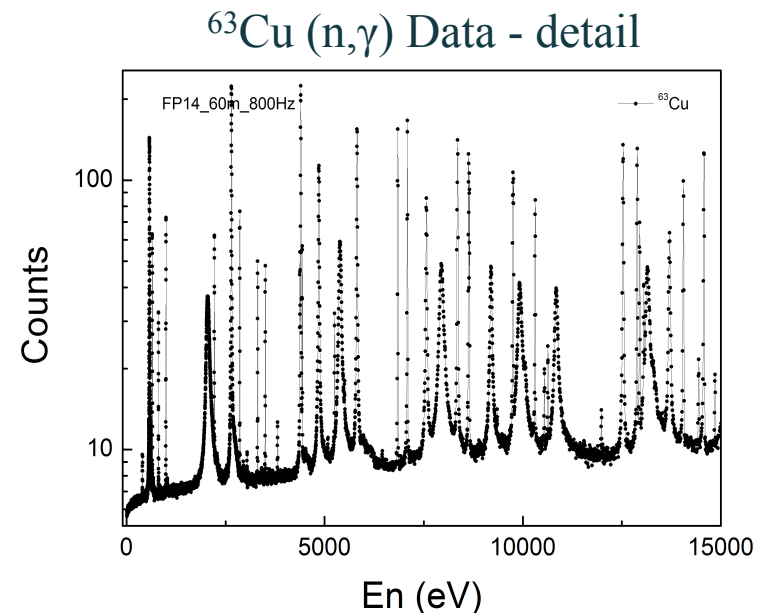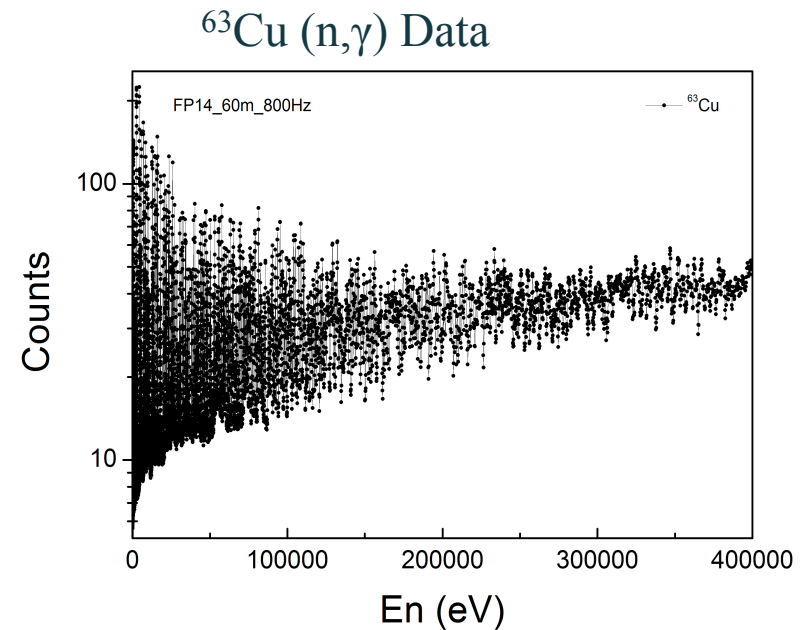
'Mining' the ORELA Data Archives for High Resolution Transmission Data

- **Retrieved high resolution data for natural and enriched Cu samples**

- **Resolved ^{65}Cu Data up to 1 MeV, ENDF resonances only up to ~150keV**

- **Resolved ^{63}Cu Data up to 200 keV, ENDF resonances only up to ~150keV**
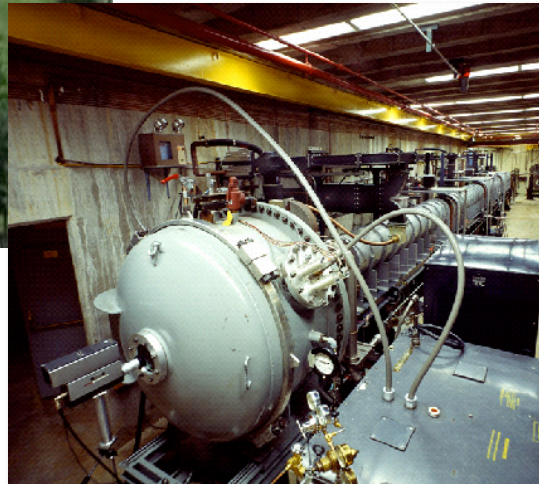
ORELA ^{63}Cu ORNL Transmission Data
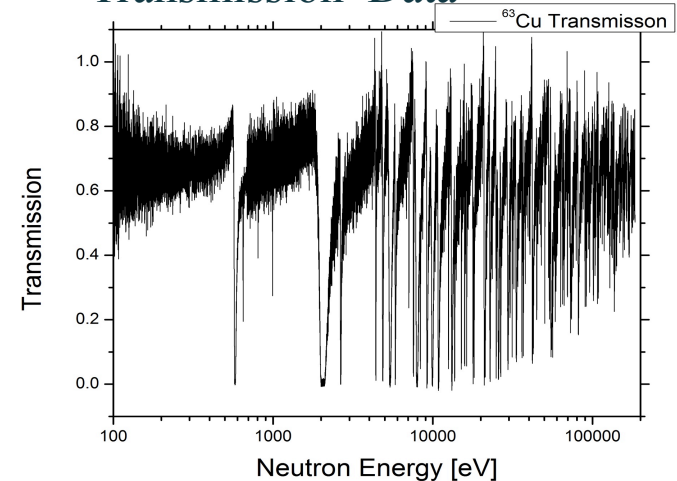
ORELA ^{63}Cu ORNL Transmission Data – Details
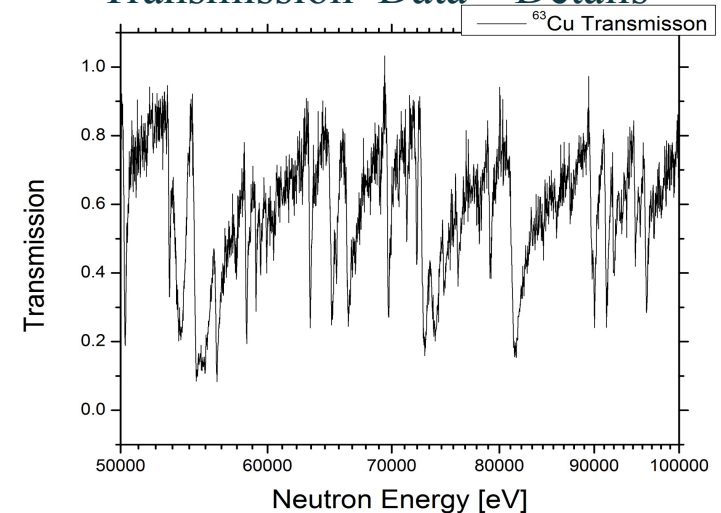
ORNL FY10 Evaluation Accomplishments
^{46}Ti, ^{47}Ti, ^{48}Ti, ^{49}Ti, ^{50}Ti and SiO_2

ORNL SAMMY R-Matrix Resonance Region Analysis Software Used to Prepare Evaluations

➤ **Used for time-of-flight cross-section data in resonance region—analysis of neutron, charged-particle cross-section data.**

➤ **Uses Bayes' method (generalized least squares) to find parameter values.**

➤ **Uses R-matrix theory, Reich-Moore approximation (default) or multi- or single-level Breit-Wigner theory.**

➤ **Generates covariance and sensitivity parameters for resonance region**

Incident particles: neutron, proton, alpha, …

Target: one type of nuclide, or many
- Multiple isotopes
- Chemical compounds
- Contaminants

Energy region:
- Resolved resonance region (RRR)
  - Total, elastic, capture, fission, inelastic, other reactions
  - Charged-particle entrance and/or exit channels
  - Angular distributions
  - Integral data (Westcott's g-factor, resonance integral, Watt spectrum average, K1, alpha)
- Unresolved region (URR)
  - Total, elastic, inelastic, capture, fission

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Resonance Parameter and Covariance Evaluation for ^{48}Ti

- Capture (40-meter) and transmission (80-meter) measurements for enriched ^{48}Ti and natural titanium performed at ORELA from 10 eV to 500 KeV

- Evaluation performed with SAMMY

- Resolved resonance parameters determined from 10^{-5} eV to 400 keV

- Evaluated Resonance parameter covariance

- Thermal cross section and resonance integral and uncertainties well reproduced

^{48}Ti thermal cross section compared to the values listed in the Atlas of Neutron Resonances

Cross Section	ORNL	Atlas of Neutron Resonance Parameters
	Resonance and Direct	
Capture	8.32 +/- 0.23	8.32 +/- 0.16
Total	12.35 +/- 0.30	12.42 +/- 0.25
Scattering	4.03 +/- 0.17	4.10 +/- 0.20
RI	3.78 +/- 0.17	3.90 +/- 0.25

⁴⁸Ti Cross Sections: Experimental and SAMMY

Thin sample:
0.0011821 at/b

Thick sample:
0.028185 at/b

Total (barns)

Total (barns)

Capture (barns)

Energy (keV)

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⁴⁸Ti Cross Sections: Experimental and SAMMY

Resonance Parameter and Covariance Evaluation for ^{46,47,49,50}Ti

➤ Resolved resonance parameters were converted from MLBW into the RM representation. The resonances were checked against the resonance parameters given in the Atlas of Neutron Resonances

➤ For ^{46}Ti a resonance at 55.67 keV with j=1/2 (l=1) was repeated. According to the Atlas of Neutron Resonance Parameters—should be at the energy 56.66 with Γ_t=0.48 eV, Γ_n=0.1 eV and Γ_γ=0.38

➤ Thermal cross section and resonance integral are unchanged

➤ Covariance Data:

  • Resolved resonance covariance data were generated with the SAMMY for ^{46,47,49,50}Ti

  • SAMMY used with option to generating resonance-covariance retroactively using the "propagated uncertainty parameter" option to include systematic data uncertainties

Retroactive Covariance Analysis Methodology
PHYSOR-2006 PAPER
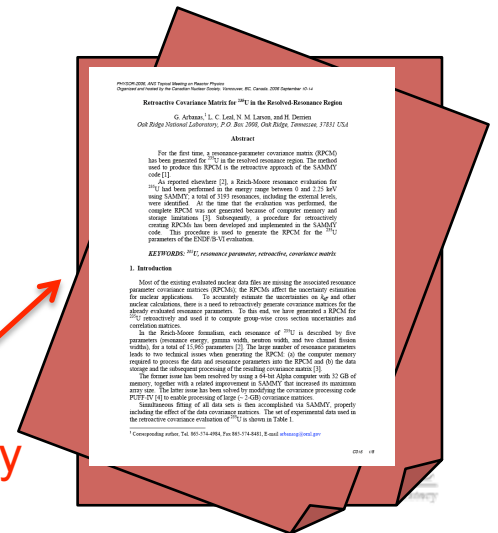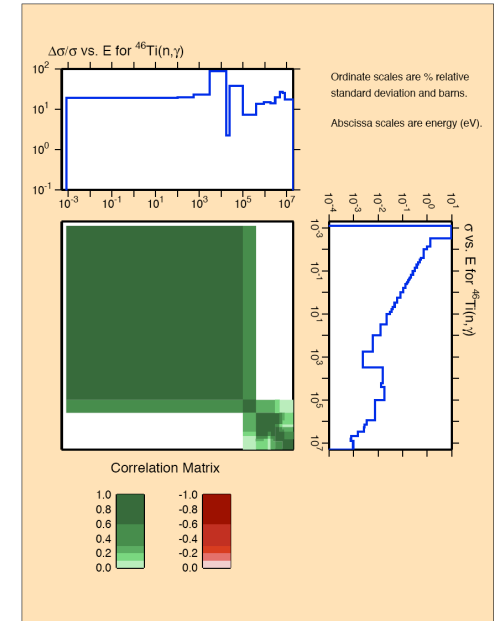
# NCSP Work to address Thermal Scattering Data Needs

- Evaluated nuclear data libraries have limited $S(\alpha,\beta)$ or thermal scattering law data for moderators important for nuclear applications (~20 moderators in ENDF/B-VII.0)

- Example NCSP thermal data needs: SiO_2, HF, D_2O, CH_2, C_2F_4, etc.

- Also, no covariance data available for $S(\alpha,\beta)$ data files currently in ENDF/B

- ORNL has been performing work with NCSU to provide thermal scattering data for moderators important for criticality safety applications

- ORNL-NCSU planning to provide $S(\alpha,\beta)$ covariance data for future thermal evaluations

ORNL work with NCSU produced new SiO_2 Evaluation in FY2010

Incoherent Inelastic Thermal Neutron Cross-Sections in Silicon Dioxide
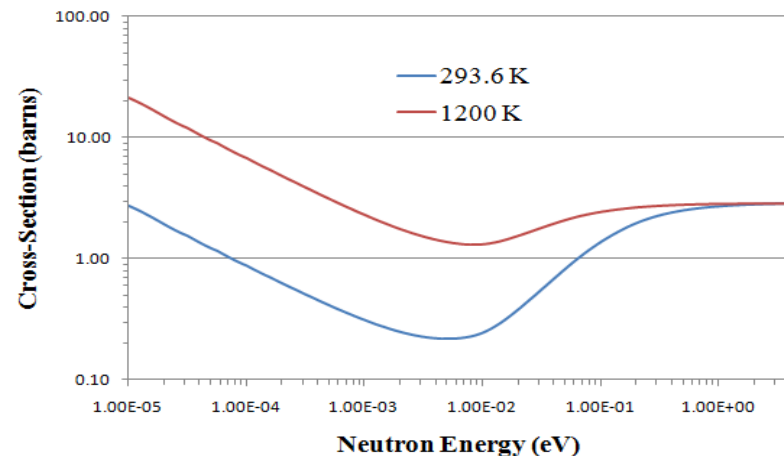
Coherent Elastic Thermal Neutron Cross-Sections in Silicon Dioxide
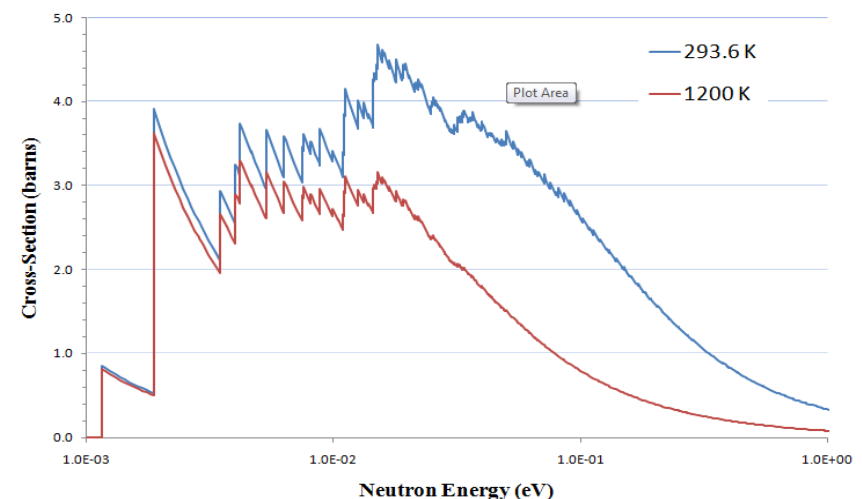
Evaluation Status for ENDF/B-VII.1

➢ ^{46,47,48,49,50}Tl (5 isotope evaluations): submitted to NNDC—ORNL (Resonance Evaluation) combined with LANL (High Energy Evaluation)—criticality benchmark testing shows improved performance

➢ SiO$_2$: evaluation submitted to NNDC—CSEWG testing in progress

➢ ^{180,182,183,184,186}W (5 isotope evaluations):

- ORNL (Retroactive Covariance Evaluation—not new resonance evaluation) combined with IAEA (High Energy Evaluation)

- Current ORNL measurement and evaluation work expected to improve resonance evaluation

➢ ^{50,52,53,54}Cr (4 isotope evaluations):

- Updated evaluations submitted in 2010 (work based on new measurements and evaluation)

- ORNL resonance evaluation coupled with FZK High Energy Evaluation

➢ ^{58}Ni and ^{60}Ni (2 isotope evaluations):

- Updated evaluation submitted in 2010 (based on new measurements and evaluation

- ORNL resonance evaluation coupled with ENDF/B-VII.0 high energy evaluation

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Evaluation Status for ENDF/B-VII.1

➤ **^{240}Pu:** submitted to NNDC October 2010—CSEWG testing in progress

- ORNL resonance evaluation (re-evaluation of existing measured data) coupled with LANL high-energy evaluation

➤ **^{55}Mn:**

- Updated evaluation submitted in 2010 to add correct File 33 covariance data for resonance region

- ORNL resonance evaluation coupled with IAEA high-energy evaluation

➤ **^{35}Cl and ^{37}Cl:** submitted in 2007

- ^{35}Cl has LRF=7 resonance format – NJOY update needed to process

➤ **^{39}K and ^{41}K:** submitted Oct 2008—little or no benchmark testing

➤ **^{19}F:** submitted Oct 2008

- New LRF=7 resonance format – NJOY update needed to process
- inelastic scattering data incorporated in resonance analysis
- New evaluation has not improved benchmark performance—but has not made benchmark calculations worse either

Evaluation Status for ENDF/B-VII.1

➢ **^{233}U, ^{235}U, and ^{238}U**: covariance evaluations submitted March 2008

- ORNL (resonance parameter covariance data) and LANL (High energy covariance data)

- ^{233}U updated file submitted in 2010 to use LANL high-energy evaluation down to top of resolved region

- Covariance data utilized in WPEC SG33 analyses and also distributed with SCALE 6 by ORNL

Summary

➢ ORNL nuclear data contribution to NCSP mission:

- Cross-section measurements for resonance region

- Nuclear modeling methods development (SAMMY)

- Cross-section evaluation and preparation of ENDF/B nuclear data files

➢ Completed multiple resonance region nuclear data measurements and corresponding nuclear data evaluations of direct importance to NCS applications

➢ ORNL FY10 Evaluation Accomplishments include new evaluations for ^{46,47,48,49,50}TI and SiO_2—submitted to NNDC

➢ Within the NCSP, ORNL sustained efforts working with ANL, BNL, and LANL to provide improved nuclear data evaluations for dissemination as new ENDF/B data libraries

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